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Assessments of primary energy consumption and its environmental consequences in the United Arab Emirates

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Abstract

Since its independence in 1971, the United Arab Emirates (UAE) took a giant leap toward achieving a high economic growth and urbanization. Consequently, primary energy consumption namely oil and natural gas has quadrupled in the past two decades such that energy consumption per capita was the highest in the world and the resulting carbon emission per capita was at least twice and 10 times higher than the developed countries and the world's annual average emission, respectively. In this paper, assessments of the UAE's primary energy consumption and its environmental consequences in the past two decades are carried out. The study covered major parameters such as urbanization, population and economic growths that influenced the country's energy consumption. Furthermore, the study suggested key remedial measures that could be deployed by local and national organizations in the country in order to consolidate their positions in mitigating country's primary energy consumption and environmental emissions. The proposed remedial measures are namely enhancing public awareness, achieving a lower population growth rate, maintaining a high economic growth rate, utilizing renewable energy resources, producing and utilizing hydrogen energy, implementing carbon sequestration technology and deploying energy management programs in various sectors.

Keywords: UAE; Energy consumption; Carbon emission; Economic growth; Urbanization

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1. Introduction

Since its independence in 1971, United Arab Emirates (UAE) started to take a huge step toward achieving a solid and sustainable economic growth as well as urban development. Subsequently, the population of the country has risen tremendously because of high urbanization and increase in the number of expatriates that are residing and working in various sectors. Currently, the UAE with a total area of 84,000 km^2 has one of the most diversified economies of all the major oil-producing Arabian Gulf states. The economic diversification was carried out through implementation of several major projects in various sectors, including refinery and petrochemicals, tourism, banking, real estate, aviation and airports, re-export commerce, and telecommunications. For instance, Dubai, which is one of the key emirates in the country has become a central hub for regional trade and finance, accounting for about 70% of the emirates' non-oil trade in 1998 [1]. Furthermore, free trade zones are established in all major emirates in order to provide a significant contribution to the gross domestic product (GDP).

According to energy information administration (EIA), the UAE's maximum crude oil production capacity is estimated to be around 2.0–2.5 million barrels per day (bbl/d). In addition, the country's natural gas production is estimated to be approximately 3 billion cubic feet per day (bcf/d), and it is set to reach 4 bcf/d in 2005. Generally, the country plays an essential role in the world energy market because it possesses roughly 100 billion barrels of proven oil reserves, which is nearly 10% of the world's crude oil supply. Moreover, the UAE possesses about 215 trillion cubic feet of natural gas, which is regarded the world's fifth-largest natural gas reserves after Russia, Iran, Qatar and Saudi Arabia [2].

With high economic and population growth rates and a fairly low energy cost, the country's energy consumption has risen tremendously in the past decades, making it one

of the highest energy consumers per capita in the world [3]. Consequently, environmental pollution and carbon emission has reached a record high despite the government's tireless effort to enlighten the public about energy conservation, implement stringent environmental regulations and schemes on various sectors and mandate tough environmental policies. Therefore, there is a dire need to strengthen energy and environmental initiatives in all energy-consuming sectors in order to be in line with other developed countries and without any negative impact on the country's economic growth and living standards.

In his study, Hessari performed analysis of sectoral energy consumption in Iran with respect to quantification of energy production and consumption as well as economic growth [4]. Moreover, he determined the projected growth rates of energy consumption and gross national product (GNP) without estimating other impacts on the Iran's energy consumption such as urbanization and population growth. Similarly, Utlu and Hepbasli [5], performed Turkey's sectoral energy study between years 1999 and 2000, based on the first and second law of thermodynamics. On the other hand, Kayz investigated renewable energy policies in Turkey and the political institutions that shape these policies [6].He quantified the available energy resources in the country, highlighted renewable energy policies and the associated institutions, and addressed the barriers for development of renewable energy. At a regional level, Wolde-Rufael [7], examined the long run and causal relationship between electricity consumption per capita and real GDP per capita for 17 African countries from the period 1971 to 2001.

The objective of this paper is to conduct an overall assessment of the UAE's energy consumption and its environmental consequences from 1980 to 2003. The analysis will cover all major parameters influencing country's energy consumption in terms of population and economic growths and urbanization. In addition to the country's energy, population and environmental projected outlooks, key remedial steps will be addressed to overcome high-energy consumption and environmental emissions and without any sacrifices on its economy.

2. Contributing parameters to UAE's energy consumption

Generally, there are three major parameters that could significantly influence the UAE's energy consumption namely population growth, high urbanization and economic growth, as depicted in Fig. 1. Environmental emissions such as carbon emission are considered a direct result of country's primary energy consumption with respect to utilization of oil and natural gas.

2.1. UAE's population and urbanization profiles

Until the last four decades of the past century, people in the country consisted of nomadic tribes living in the deserts and people living on the coasts. The nomadic tribes were concerned with farming, nomadic camel herding, and tending date gardens and associated agriculture in the oases, sheep and goat herding where pasture and water supplies permitted. On the other hand, people on the coasts were involved in fishing and fish drying, pearl diving and trading, which included overseas dhow journeys and dhow building. In response to the increased demand for pearls, many more families settled permanently in the coastal villages, which began to grow its importance and influence,

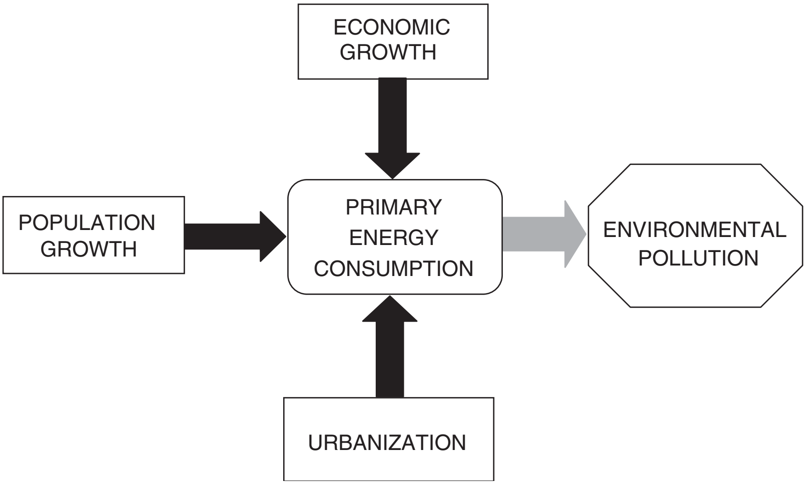


Fig. 1. Parameters contributing to UAE's primary energy consumption and environmental pollution.

particularly Abu Dhabi and Dubai. Others would live on the coast during the 4 months of the main pearling season, from May to September, and return to the desert in winter. Generally, life was quite harsh especially in the desert where the water was considered a prime importance for people's livelihood. Similar difficulty also existed on the coasts especially when it came to diving for pearls where the diver has to dive up to 40 m in order to get the pearls from the bottom of the sea [8].

After the discovery and production of crude oil in the early 1960s and particularly after its independence in 1971, the UAE achieved unprecedented high economic returns from sales of crude oil. This in turn led to more investments in the oil industry as well as building infrastructure, banking, commerce, tourism and real estate in order to compete with the other developed Asian states such as Singapore and Hong Kong. Originally, UAE's population was in few hundred thousands when it got its independence, which was the starting point of attracting more expatriates from different parts of the world in order to run its economy, business as well as industry. Through massive migration of expatriates to the country in few years, its population almost doubled every 5 years as depicted from Fig. 2, which presents the country's economic growths in the past 23 years as well. Currently, the total UAE's local population makes up only 20% of the overall population, which consists of expatriates coming from Middle Eastern countries (40%), South East and Far East Asian countries (30%), and the rest 10% are coming from other nations such as EU countries, Australia and the USA [2,9]. On the average, the expatriates occupied nearly 90% of the country's work force in the past two decades.

In 1980, the UAE's population was estimated to be 0.70 million inhabitants, which doubled within 5 years period. By the year 2000, the country's population reached 3.25 million inhabitants, which was a direct result of increase in the number of expatriates joining the work force in the oil booming economy. On the other hand, the percentage of UAE's local population remained almost steady at a 20% of the total population. High rates of urbanization and living standards have significantly transformed the country to be one of the most urban and developed countries in the world in the present time.

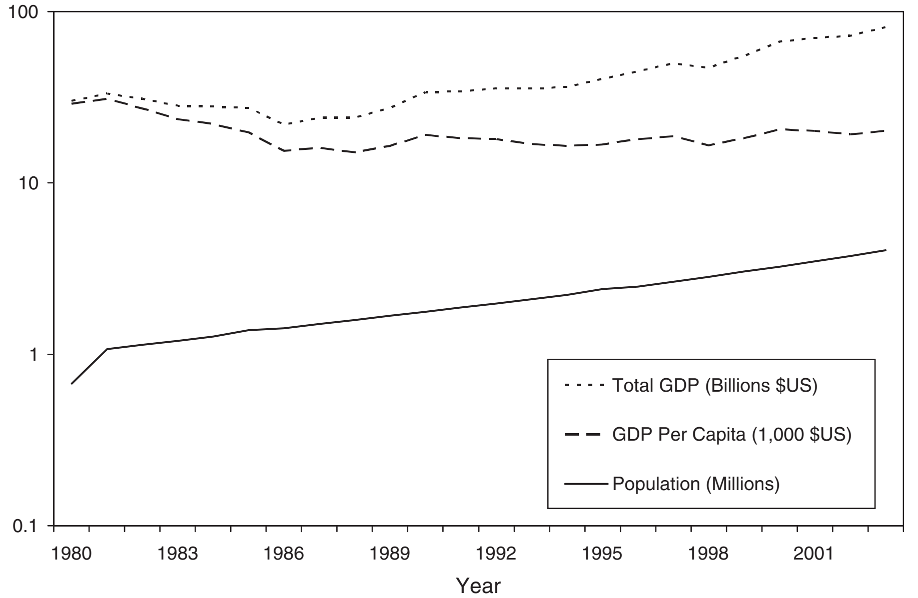


Fig. 2. UAE's GDP and population growth from 1980 to 2003.

2.2. *UAE's economic profile*

From 1980 to 2003, the UAE's GDP raised tremendously from 30 billion $US in 1980 to 81 billion $US in 2003, marking an annual average growth rate of 4.9% as shown in Fig. 2. On the other hand, the GDP per capita was regarded to be unsteady during the same period, primarily due to an abnormal growth in the country's population and revenues generated from sales of crude oil. For instance, the average GDP per capita in 1980 was about 29,000 $US, which dropped significantly in the mid 1980s to reach 15,000 $US/capita, as a result of lower revenues generated from the sales of crude oil which reached 5 $US/barrel in 1986. Then, the country's GDP per capita gradually started to rise in the early 1990s to reach 20,000 $US/capita in the year 2000. According to CIA World Factbook [10], the UAE's GDP per capita in 2003, was estimated to be 23,200 $US/capita, which was ranked 31st in the world of 231 nations.

Although the UAE's economy in the recent years has become more diversified and less dependant on oil revenues than most of the OPEC members, the instability of oil price caused by fluctuations in the $US Dollars as well as political conflicts in the region has hindered the economic growth of the country to some extent in the past decades. For example, the revenues generated from sales of crude oil have declined from 19.4 billion $US in 1980 to 6.9 billion $US in 1985 and then rose up to 26.15 billion $US in the year 2000. Without a doubt, these figures sharply reflected on the total country's GDP, which declined from 30 billion $US in 1980 to 21.8 billion $US in 1986 then later increased to 66.6 billion $US in the year 2000 [11,12].

When the crude oil price reached a record low in 1986, the UAE started to take some drastic measures to diversify its economy through tourism, trades, real estate, banking and commerce. This diversification has significantly helped to cushion the economic impact of

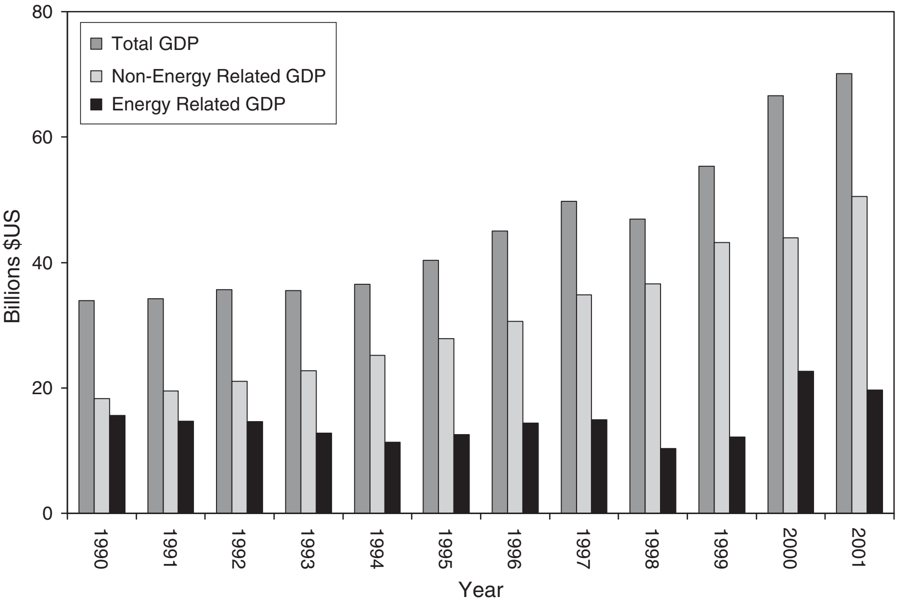


Fig. 3. Breakdown of UAE's GDP in the last decade [2].

the collapse of crude oil price of 15 $US/barrel in 1998. The breakdown of UAE's GDP in the last decade shown in Fig. 3, illustrates that the country's economy is heading toward a balanced and sustainable sources of income rather than complete dependency on energy intensive industries [9]. For example, non-energy related GDP accounted 54% of country's total GDP in 1990, while the rest 46% was contributed by energy related exports, which were substantially reduced to 28% in 2001 while the rest 72% was contributed by non-energy related industries.

The key non-energy related sector that significantly contributed to the country's GDP in the past decade was the manufacturing sector with 26.7% of the total non-energy related GDP. Typical manufacturing industries included construction materials, cement, aluminum, chemical fertilizers, pharmaceuticals, paint products, clothing, furniture, paper and carton, plastics, fiber glass, processed metals and food-processing. Following the manufacturing sector, came the tourism sector accounting 20.9% of the total country's GDP. Then, government service sectors such as health, education and public services accounted 19.5% and transport, storage and communication sector accounted 13.2% and construction sector with 12.8%. On the other hand, agriculture contributed the least with 6.9% of the total GDP [9]. It should be emphasized that if the country follows the above trend in the next 5 years, energy related GDP will be accounted less than 17% of the overall country's GDP in the next decade.

3. UAE's energy profile

To date, the United Arab Emirates has been playing an important role in the organization of the petroleum exporting countries (OPEC) since it joined the organization in 1971. Beside the UAE, OPEC consists of 10 major oil-producing members, which are

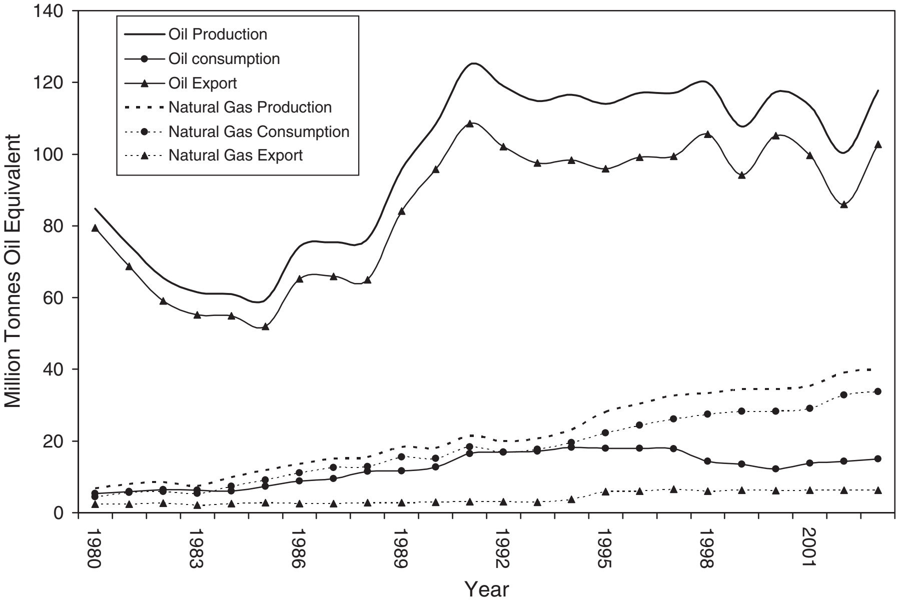


Fig. 4. UAE's oil and natural gas trends from 1980 to 2003.

Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia and Venezuela. These 11 members are collectively supplying about 40% of the world's oil output, and they are possessing more than three-quarters of the world's total proven crude oil reserves [11].

Fig. 4 presents the trends of UAE's primary energy namely crude oil and natural gas from 1980 to 2003. On the average, 87% of the country's produced crude oil is exported overseas mainly to East Asia and the Pacific such as Japan. Generally, the country's share of oil production was inconsistent and on the low side during 1980s as a result of low cost of crude oil. However, oil production became somewhat steady during the 1990s with a consistent level of 100 MTOE/year and with a fairly stable oil price of 20$/barrel [12].

Roughly, 18% of the country's produced natural gas is exported overseas mainly to East Asia while the rest is consumed locally for electricity production and water desalination. Moreover, the UAE has started to work with Qatar on a Dolphin gas project, which covers Qatar, the UAE and Oman with a projected cost of $8 billion over the next 6 years. This project is expected to be the world's largest gas program and a major strategic initiative designed to stimulate industrial investments in the UAE and develop an extensive gas supply and infrastructure system in the Gulf region. The project is anticipated to deliver Qatar gas to the UAE, Oman and eventually South Asia via an undersea pipeline [13].

Throughout the past 23 years period, the production of crude oil rose from 85 MTOE in 1980 to 118 MTOE in 2003, marking a small increase in the average annual growth rate of 1.7%. About 13% of the produced crude oil was utilized locally particularly in the transport sector. Conversely, the production of natural gas rose from 6.8 MTOE in 1980 to 40 MTOE in 2003, marking a substantial rise in the average growth rate of 9.1% per year. About 95% of the domestically used natural gas is allocated for power generation and water desalination while the rest is allocated as feedstock for the petrochemical industry.

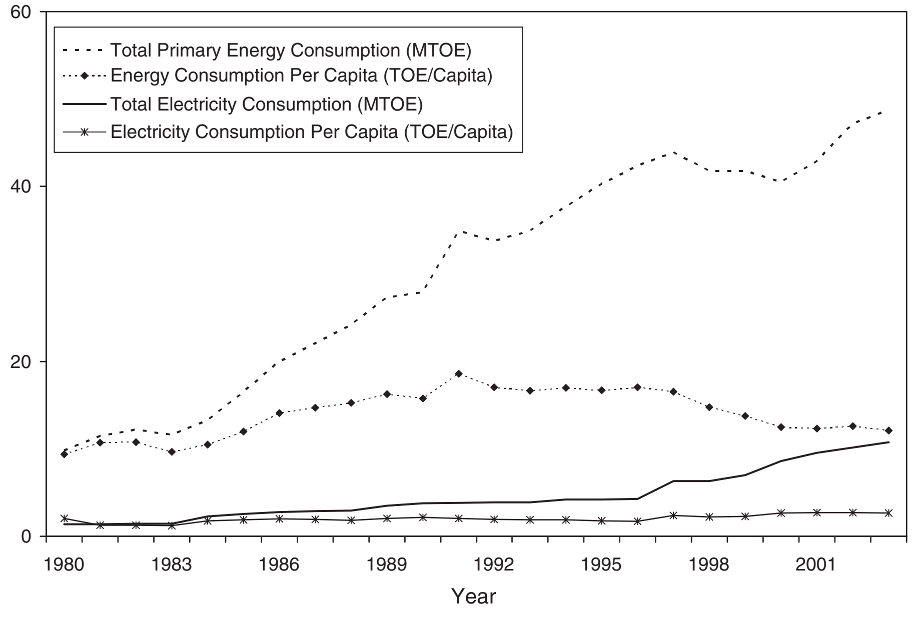


Fig. 5. UAE's energy and electricity consumption from 1980 to 2003.

Liquefied natural gas (LNG) constitutes the main exports of natural gas and liquefied petroleum gas (LPG) shipped mainly to Japan and other East Asian countries.

The UAE's primary energy consumption boomed so rapidly during the 1980s and 1990s, as depicted from Fig. 5. For instance, energy consumption has doubled within 8 years in the 1980s, and then doubled again in the mid 1990s as a result of a major increase in the population growth despite the country was going through an economic slump in the period from mid 1980s to early 1990s. For the same reason, an abnormal increase in the electricity consumption is noticed such that the consumption increased from 1.4 MTOE in 1980 to 3.8 MTOE in 1990 to 8.6 MTOE in the year 2000. A plausible explanation concerning this trend is that beside the population growth, the country is located in the hot and arid region, which requires intensive cooling all year around. Therefore, continuous cooling of residential, industrial commercial and all public and private facilities was the main concern of utilities sector, keeping in mind that major energy-consuming appliances such as refrigerators and A/C's require a large quantity of electric power [14]. However, it should be noted that the annual average electricity consumption per capita was maintained at an average rate of approximately 2 TOE/capita. Increasing the indoor temperature set-point of air conditioning systems in the commercial and residential buildings could substantially reduce the electricity consumption and it might be regarded as one of the effective measures that could be employed on a wider scale throughout the country [15].

The UAE, which is located in the arid region, where scarcity of water is the greatest issue facing the country, is obliged to desalinate water for drinking and irrigation purposes. Presently, the country is considered one of the world's biggest consumers of water with a daily average consumption rate of 90 gallons/capita. It produces about 12.5% of the world's total desalinated water and with further investments planned; this figure is set to rise. Today, desalination produces over 70% of total potable water needed in the UAE,

with over 420 million gallon per day going to the domestic network [16]. Theoretically, water desalination requires about 0.86 kWh/m^3 of desalinated water and the actual desalination process such as reverse osmosis or multi-stage flush would require about 5 kWh/m^3 of desalinated water. Therefore, a considerable portion of the country's energy consumption is devoted to various desalination processes [17].

Fig. 6 shows that the UAE's energy consumption per capita was considered the highest in the world compared to other developed regions during the period from 1980 to 2003.

As previously illustrated, economic growth, population growth and urbanization are the three major parameters that contributed significantly to country's high-energy consumption. Among the above contributors, economic growth and higher urbanization demonstrated to pose the greatest influence on the annual energy consumption, which ranged from as low as 9 TOE/capita to as high as 18 TOE/capita over the 23 years period. On the average, UAE's energy consumption per capita is about 6-and 9-folds greater than energy consumption per capita in the Middle East and the world, respectively. Moreover, the country's energy consumption is four and two times more than EU countries and the US, respectively. Definitely, these astonishing rates become more serious when we translate them into carbon emission per capita, which is regarded to be the highest in the world.

The annual average growth rate of UAE's energy consumption per capita in the past two decades was 1.4%, which was far greater than any nation in the world. On the other hand, growth rates of the USA and EU countries demonstrated to be steady from 1980 to 2003 because of adopting stringent energy conservation schemes especially in the industrial and commercial sectors. By the same token, the average energy consumption per capita in the Middle Eastern countries as well as the world remained at consistent rates of 2 and 1.6 TOE/capita, respectively.

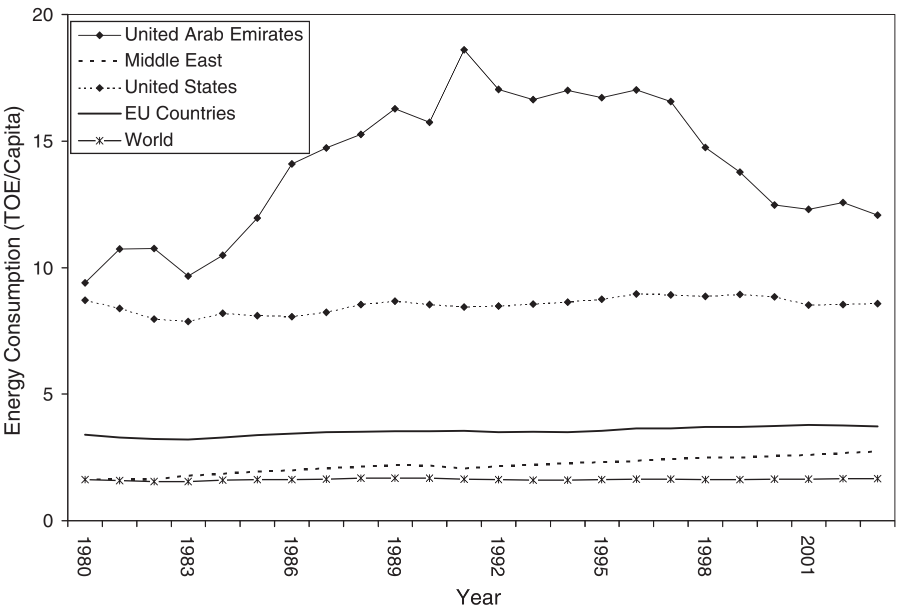


Fig. 6. UAE's energy consumption per capita compared to other regions from 1980 to 2003.

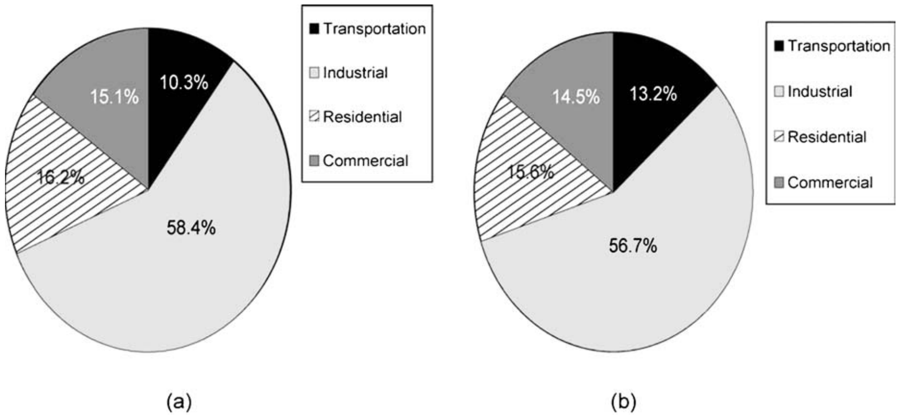


Fig. 7. UAE's sectoral (a) energy consumption and (b) carbon emission in 1998 [2].

In Fig. 7(a), the sectoral energy consumption in the country in 1998, as a sample case, demonstrated that the industrial sector consumed 58.4% of the total primary energy consumed that year [2]. Electricity generation and water desalination were considered the primary energy-consuming sub-sectors in the industrial sector, followed by other energy intensive industries such as building materials, aluminum, fertilizers and pharmaceutical industries. The residential and commercial sectors had almost an equal share of 16.2 and 15.1% of the total primary energy consumption, respectively. Conversely, the transportation sector demonstrated the lowest share of 10.3% of the country's overall energy consumption. However, this percentage is anticipated to double in the next decade due to predicted increase in the population [18]. Without a doubt, the environmental impact of these figures would be very severe especially with respect to carbon emission [2].

4. Environmental issues

Increasing urbanization, population growth rate and expanding industrialization, particularly in the oil industry, vehicles utilization and other anthropogenic activities, have increased the levels of hazardous air pollutants such as carbon monoxide, nitrogen oxides, sulphur dioxide, hydrogen sulphide, ozone, hydrocarbons, chlorofluorocarbons, lead and other particulate matters. Generally, high-energy consumption that took place during the past 23 years period has negatively reflected on the environmental front. For instance, the sectoral carbon emission in 1998 as a sample case, which is depicted in Fig. 7(b), clearly indicates that the industrial sector was the main contributor to the overall environmental emissions with 56.7% of the total emission. With rapid economic growth, the industrial sector would have a greater share of energy consumption and eventually a greater contribution to the carbon emission in the near future, especially if no drastic measures are taken to curb such environmentally risky trends. As previously demonstrated, electricity generation and water desalination are primarily responsible for most of the pollution caused in the industrial sector followed by other energy intensive industries such as aluminum foundry, pharmaceuticals, building materials and cement industries.

Obviously, the UAE's carbon emission per capita shown in Fig. 8 indicates the seriousness of the environmental issues that are facing it in the present time. Throughout

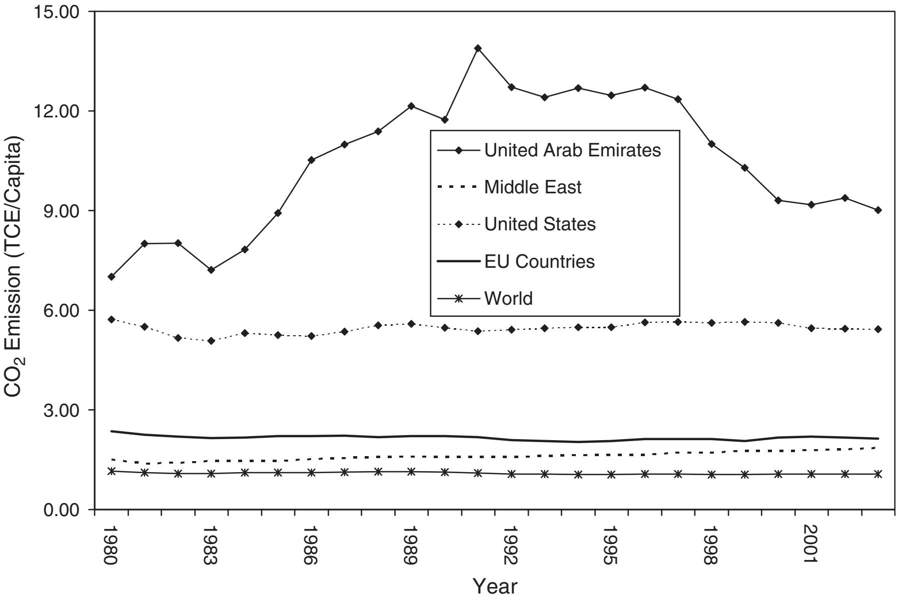


Fig. 8. UAE's carbon emission in comparison to other regions from 1980 to 2003.

the past 23 years period, the emission per capita was at least twice of the developed countries such as the US and EU countries with an annual average emission of 10.5 ton carbon equivalent (TCE) per capita. The country experienced the highest carbon emission during the period from the late 1980s until late 1990s, as a result of a fairly low energy cost as well as high economic growth with an annual average emission growth rate of 4.9%. Surprisingly, the world's annual average emission was at a marginal rate of 1.1 TCE/capita during the same period. One of the key remedies to the above dilemma is usage of technologies to capture CO_2 for either safe, long-term storage or use as a commercial commodity or carbon sequestration technologies.

Throughout the past two decades, gaseous fuels posed to be the most prominent types of fuels that contributed significantly to the UAE's carbon emission, as illustrated in Fig. 9. The country's total annual average carbon emission is calculated to be around 23.5 mton carbon equivalent (MTCE). Roughly, gaseous fuels contributed 50% of the total emission with 12.9 MTCE/year, as a result of the country's heavy dependence on its resources of natural gas for domestic purposes. Liquid fuels demonstrated to be the second most contributing fuels to the overall emission with an average emission of 7.8 MTCE. This type of fuel consists of crude oil, LNG and LPG that are mainly used in residential and commercial sectors. Moreover, UAE's high rate of vehicle utilization per capita compared with other countries within the Gulf region is another major factor of having a high carbon emission from liquid fuels specifically from crude oil and its derivatives.

Emission resulted from cement production as depicted from Fig. 9, demonstrates a significant increase throughout the 23 years period with an average growth rate of 13% per year. This drastic increase in cement production is attributed mainly to the massive construction efforts by the government as well as by the local authorities to establish an adequate infrastructure to the highest possible standards, in order to vitalize the tourism

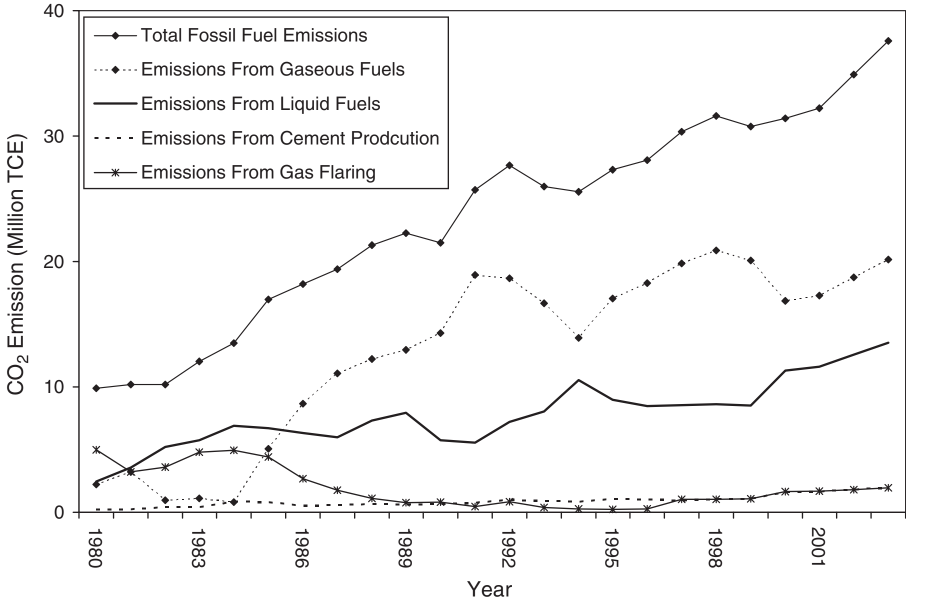


Fig. 9. Breakdown of UAE's carbon emission from 1980 to 2003.

and real estate industry, and to fulfill the tremendous real estate demand, which has drastically increased at an irregular rate. However, Abu Dhabi National Oil Company (ADNOC) has been steadily phasing out the flaring-off of associated gases in favor of liquefaction and sulphur removal, in order to help conserve resources, reduce the air pollution and improve air quality, setting an example for other industries such as cement factories.

5. Outlook on country's economics, energy and environment

The projected UAE's economic; energy and environmental status in the next 10 years are presented in Table 1. The analysis was performed by taking the average growth rates of the country's GDP, primary energy consumption and carbon emission in the past 23 years period. Without a doubt, the country is heading toward a considerable economic growth coupled with high primary energy consumption, which could consequently trigger a future environmental catastrophe, if no effective and immediate measures are taken to curb the emissions.

The UAE's population is expected to double within 10 years, if it experienced a similar economic growth that occurred in the past two decades as well as high living standards and increase in the number of expatriates to join the workforce. This alarming rate could lead to a marginal economical slump in terms of GDP/capita, while maintaining a high rate of primary energy consumption, which is also predicted to double in 2015. Consequently, a 100% hike in the rate of carbon emission would be anticipated by the same year. However, carbon emission per capita is set to maintain at a steady rate of 8.7 TCE/capita, which still could be considered higher than any developed countries, especially Japan and EU countries have strongly committed themselves to implement the Kyoto Protocol [19].

Table 1
Projected UAE's population, GDP, energy consumption and carbon emission in the next 10 years

Parameter	2005	2010	2015
Population (million)	4.6	6.2	8.4
Total GDP (Billion $US)	86.5	109.7	139.1
GDP per capita (1000 $US)	18.8	17.6	16.5
Total primary energy consumption (MTOE)	55.5	80.7	117.3
Energy consumption per capita (TOE/capita)	12.1	13.0	14.0
Total carbon emissions (MTCE)	40.1	54.2	73.1
Carbon emissions per capita (TCE/capita)	8.7	8.74	8.7

It should be emphasized that the values presented in Table 1, represent extreme cases where no energy conservation schemes are implemented coupled with high economic and population growths. However, the rates could drastically fall if the country adopted stringent energy conservation measures and effectively implemented utilization of renewable resources such as solar and wind energy at substantial rates. Moreover, country's living standard could also influence the energy consumption rate with respect to life-style, diversification of modes of public transportation and reduction in utilization of vehicles. Future number of expatriates coming to the country and joining the workforce could significantly influence the overall economic, energy and environmental pictures as well.

6. Remedial measures

To date, numerous economic, energy and environmental measures were taken by various UAE organizations, and municipalities to face the abnormal demand on energy and its environmental consequences. However, there are additional steps that need to be considered to consolidate the positions of these organizations in conserving energy and reducing environmental pollution without any sacrifices on the UAE's economic growth. Therefore, this section of the paper will address the remedial measures that are taken by the UAE's local and national organizations concerning energy and environmental issues as well as proposed additional steps that the country should take in achieving these objectives. These measures are namely enhancing public awareness, achieving a lower population growth rate, maintaining a high economic growth rate, utilizing renewable energy resources, producing and utilizing hydrogen energy, implementing carbon sequestration technology in power plants and deploying energy management programs and schemes in the industrial, residential and commercial sectors.

6.1. Enhance public awareness

In the past few years, the UAE has taken few steps to face the growing energy demand along with high level of environmental pollution. For instance, involvement of governmental organizations such as Federal Environmental Agency (FEA), environment research and wildlife development agency (ERWDA), department of environment and protected areas (DEPA), local municipalities and other non-government organizations, in a nationwide environment monitoring and impact assessment programs to deal with air pollution. In addition, several energy and environmental conferences are organized

annually in order to enhance the public awareness [20]. Moreover, the country organizes a bi-annual Zayed International Prize for the environment with awards totaling $1 million Dollars, which is considered the most prestigious award in the world. The aim of the award is to promote sustainable development through various environmental protection initiatives [21].

In the residential sector, Dubai municipality started to mandate all major building contactors to use the insulated bricks in all construction projects after it kept it optional for several years. The aim of the imposed requirement was to conserve electrical energy by approximately 40% and hence to reduce the emission by a considerable rate [22]. Furthermore, local municipalities have taken considerable steps in promoting usage of energy saving building materials and devices such as windows, pipes and lightings and A/C controllers as well as district cooling technology. However, there are further measures that could be taken to improve public awareness in the residential and commercial sectors such as financial incentives and low interest loans on constructing houses or buildings with major energy saving building materials. Moreover, local municipalities should form offices that will process all residential and commercial energy related issues such as mandating and providing consultation on energy saving materials, promoting and giving incentives on recycling of residential as well as industrial wastes and usage of treated water rather than potable water for irrigation proposes. Sadownik and Jaccard, who proposed community energy management for China [23], pinpointed some of the above suggestions and measures in extensive details.

6.2. Achieve a low population growth rate

Roughly, expatriates coming from various parts of the world, with some having a relatively high international exposure, occupy 90% of the country's workforce. To overcome the unemployment rate of approximately 2.4%, which is the lowest in the Arab world, the country could nationalize crucial administrative positions and recruit more locals in various sectors. Moreover, local workforce could go under intensive training programs and obtain quality education to achieve the required skills. Many governmental and local organizations as well as private sectors have already started implementing such programs and initiatives. The government to lower population growth can implement additional steps, which are taken by other nations such as Saudi Arabia, and these steps are beyond the scope of this paper.

6.3. Maintain a high economic growth rate

It is suggested that the UAE could gain a huge benefit from the sales of crude oil, if it adopted a scheme through which the price of oil is linked to a basket of major currencies in order to stabilize the price in the energy market [12]. In addition, the country should also continue diversifying its economy rather than depending on the sales of crude oil and natural gas. Besides, the country should always encourage foreign investments, which will maintain its economic growth and create jobs.

Generally, the UAE is considered a tax-free country and it does not impose any taxes on expatriates, who are enjoying most of the services provided to them free of charge. Therefore, it is essential to impose a certain income tax on the expatriates, through which the country could generate considerable revenue that could be allocated to improve its

services that are provided to the public. However, many business owners as well as government officials may dispute this suggestion since it would discourage skilled workers of joining the country's workforce especially majority of these expatriates are regarded to be the backbone of the country's continuous growing economy.

Every month, expatriates, who are joining the workforce, send a significant portion of their income, which is linked to the strong $US Dollar to their respective countries and without any governmental taxes imposed on such transactions. Consequently, the country since its independence has lost a huge sum of its strong currency through such transactions conducted by the expatriates. For instance, it was reported that the working expatriates in the country sent approximately 16.1 billion of UAE Dirhams (4.4 billion $US Dollars) to their respective countries in 2003 [9]. Therefore, it would be essential to impose a nominal tax for such financial transactions in order to preserve UAE's hard currency and achieve substantial financial gains. Again, many people, who are residing and working in the country as well as many business owners, may not appreciate this suggestion even though it would create a huge economical benefit to the country. By taking the steps stated above, the country would eventually reduce its abnormal population growth and achieve tremendous financial gains.

6.4. *Utilize renewable energy*

One of the key measures that could be undertaken toward a sustainable development and without any negative influence on the environment is utilization of the renewable resources available in the country. The UAE has a huge potential of solar energy with an annual average solar insolation exceeding 8.5 GJ/m^2 year [24]. In addition, the strong opposition to developing renewable sources of energy has been fading in recent years since the oil-rich country has always depended on conventional sources as the main source of income and power generation [25].

Some governmental as well as local organizations have already taken some steps in exploiting solar energy in various applications. For example, Abu Dhabi National Oil Company (ADNOC), water and electricity departments, local municipalities and the telecommunications company ETISALAT have already incorporated solar technology into their systems. The establishment of solar power links in remote desert regions has increased the coverage area of mobile phones, leaving only very few areas where it cannot be used [26]. Moreover, a 100-flat apartment building in Dubai, which was built last year, was the first building in the Middle East to use solar power in order to cool the building by day, and to cut utility bills by at least a third. The typical pay-off period for solar energy is 3–5 years. When the cost plus the price for the kilowatt per hour is calculated, most of the solar energy-based systems achieve a payback of less than 3 years. Furthermore, in an effort to utilize solar energy, Dubai Municipality erected solar-powered parking meters as well as some road signage in and around the city.

Climatologically, the country is located in the hot and arid region, which could significantly affect the efficiency of PV cells especially during the summer when the weather in some cities reaches 50°C [27]. However, solar thermal energy conversion system through solar-concentrators could be the best alternative method of utilizing solar energy for desalination and power generation as well as hydrogen production for energy storage purposes. Solar stills could be another form of solar energy that might be exploited for water desalination purposes in the remote areas.

Wind energy is another major renewable resource that could be utilized in various applications throughout the country. Some parts of the UAE have an average wind speed of more than 8 m/s, which is very attractive for power generation purposes through wind turbines [28]. Recently, the government of Abu Dhabi opened the first wind power plant built at a cost of 2 million Euros, and it could embark additional units in the near future. The plant has a capacity to generate 850 kW of electric power and it can achieve a maximum capacity with wind speeds of 12–14 m/s. Germany's Dornier Consulting and GTZ who will operate the plant for 2 years, undertook the landmark project [29].

In the emirate of Al Fujairah, engineers of a Spanish-based wind energy giant named Energia Hidroelectrica de Navarra (EHN) have been investigating the feasibility of utilizing wind power in the emirate for the past 2 years. They have been working on the first of seven solar-powered wind measurement towers, which will decide whether the emirate can sustain four wind farms for generating electricity. Data will be monitored and analyzed during the 18 months period by EHN's engineers with the Fujairah Department of Industry and Economics (FDIE) and UAE University in order to determine the economic feasibility of producing electricity from wind turbines. After data analysis, wind farms with power generation capacities ranging between 130 and 200 MW of electricity per year, will be erected in the emirate. The farms are expected to be set up in the north of Fujairah near Dhadnah, Masafi, Fujairah city and south of the emirate [30].

Although the above works conducted concerning utilization of renewable energy in the country, the actual energy utilized does not even make 1% of the total consumed energy in the UAE [2]. The country is far behind in utilizing such abundant resources due to massive availability of fossil fuels, as explained earlier. Therefore, the country should seriously adopt utilizing solar and wind power on a wider scale especially in the remote areas.

6.5. *Produce and utilize hydrogen energy*

Many scientists, energy economists, and energy policy makers believe that hydrogen energy, which possesses significant attractive characteristics such as being environmentally clean, storable, transportable and inexhaustible, could play a key role in fulfilling the future global energy demand and without any environmental sacrifices. It can be produced from either conventional energy resources (oil, natural gas and coal) or non-conventional energy resources such as nuclear, biomass, solar, wind energy and hydro energy. Hydrogen energy produced from natural gas steam reformation process could be the most appropriate method for the UAE, which has substantial reserves of natural gas [31]. Therefore, the country could play an important role in supplying hydrogen energy to the developed countries such as Japan rather than supplying it with a pure natural gas. Moreover, hydrogen production through electrolysis process from renewable resources such as solar and wind energy, could be another alternative that the country can exploit. For example, the country could partially fulfill its energy demand through solar hydrogen energy systems despite the low conversion efficiencies of the photovoltaic cells (PV) to power the electrolyzer [24].

Experimentally, natural gas is regarded the least polluting fossil fuel as opposed to oil and coal. Typically, natural gas used in the reformation process contains mixture of various components such as methane (CH_4), ethane (C_2H_6), propane (C_3H_8) and other types of hydrocarbons, carbon dioxide (CO_2), etc. which results difficulty in predicting the performance of the plant [32]. Therefore, hydrogen production through renewable

energy would be more environmentally attractive as compared to natural gas steam reformation [33].

Presently, utilization of hydrogen energy to run fuel cells for a clean power generation has gained a worldwide attention. Fuel cells especially proton exchange membrane fuel cells (PEMFC) have been playing a significant role in the industrial, utilities and transportation sectors of many developed countries such as Japan, USA and Germany. Some reports suggest that the government of UAE must adopt a scheme associated with introduction of proton exchange membrane in electric utilities, transportation and residential and commercial sectors in order to achieve greater economical and environmental benefits in terms of fossil fuel savings and environmental pollution reduction [18,34,35].

6.6. Implement carbon sequestration technology

Mitigation of the country's carbon emission must be considered the prime objective of all governmental organizations as well as local municipalities. Therefore, appropriate schemes should be adapted in order to reduce the emission with respect to implementation of carbon sequestration technology, where carbon and other greenhouse gases can be captured at the source (i.e. power plants, industrial processes) and removed from air. The captured gases can be stored in underground reservoirs, absorbed by trees, grasses, soils, and algae, or converted to rock-like solid minerals called carbonates. Options are also being explored to enhance dissolution of CO_2 in oceans; however, these options are still far from being considered viable due to the uncertainty regarding their potential environmental impacts [36]. Enhancement of natural processes to increase the removal of carbon from the atmosphere (i.e. forestation) could also be considered [37].

Currently, the cost of emission reduction through carbon sequestration technology is greater than that of overseas projects and international emissions trading. However, this technology is more economically attractive than deployment of domestic energy conservation and renewable energy utilization. Furthermore, it is widely anticipated that the cost of carbon sequestration would fall because of intensive R&D in this field with respect to materials, exploitation of storage methods, and dissolution enhancements [38].

6.7. Deploy energy management programs

On a national level, energy management can be effectively implemented with respect to all energy and industrial sectors such as utilities, oil and natural gas companies, cement and building material factories. For instance, in the utilities sector, the government aught to be more focused on cogeneration technology and energy conservation schemes and maximum exploitation of sustainable energy supply from renewable resources. Furthermore, utilities companies must develop and evaluate alternative long-term plans to meet customers' demand for energy requirements during a specific period (about 15–20 years) and recommend options that ensure flexibility to adapt economically and effectively to a range of uncertain future conditions [39]. Creating energy auditing bureaus in order to monitor sectoral energy utilization as well as initiating low interest loans, aids and financial incentives for utilization of renewable resources, must be of prime importance to the governmental organizations. On the other hand, subsidies provided to various energy

programs within the energy sector particularly oil companies must be reduced in order to conserve energy and to promote alternative energy sources.

In 1999, the FEA issued Federal Law No. 24 on the Protection and Development of the Environment, which was passed by the UAE's former president His Highness Sheikh Zayed bin Sultan Al Nahyan. This law included 101 articles dealing with general protection of the environment as well as specific chapters on water, soil, noise and air pollution, handling hazardous substances and hazardous wastes, protected natural reserves, environmental disasters and the penalties for violation of any of these articles. The law aimed to achieve protection and conservation of the quality and natural balance of the environment, control of all forms of pollution and avoidance of any long-term harmful effects resulting from economic, agricultural, industrial, development of natural resources. Moreover, the law was set to conserve biological diversity in the region of the state, to protect the society, human health and the health of other living creatures, and to comply with international and regional conventions that are ratified by the state [16].

In addition to the above steps, the country took further measures to enforce environmental regulations on industrial, transport as well as residential and commercial sectors. For example, the Jebel Ali Free Zone in Dubai started to implement sets of international environmental standards for companies within the premises to adhere with such guidelines. Similarly, the emirate of Dubai in 1991 passed sets of environment protection regulations that cover disposal of wastewater, air pollution, noise pollution and protected areas for wildlife and a number of technical guidelines that have been issued by Dubai Municipality to supplement this local order.

Al Iriani [14] presented an excellent summary of UAE's utilities sector and the electricity demand-side management (DSM) programs that could be adopted in the country. These programs aimed at reducing the growing need for electricity power that increases the dependency on primary energy, which causes severe damages to the environment. Moreover, his work considered the relationship between climate conditions and electric energy consumption.

In the past 15 years, the United Arab Emirates has spent nearly $\$20 \times 10^9$ \$US Dollars on roads, highways, bridges and tunnels. The total paved highways connecting the seven emirates are estimated to be around 5000 km. The objective of building these facilities was to ease vehicular flow and to shorten traveling time between the cities. The demand on internal combustion vehicles has been increasing rapidly with an annual growth rate of 6%. The current ratio of number of utilized vehicles per person is one vehicle per six persons, which is anticipated to reach one vehicle for every two persons in 2025 [18]. Therefore, energy management schemes in the transportation sector must be effectively applied. Currently, the country set certain limits of gaseous pollutants in accordance to Gulf Cooperation Council, GCC board of directors [18]. However, the rapidly increasing density of vehicular traffic means that the federal capital cannot rely on this situation. The Abu Dhabi government introduced more rigorous exhaust emissions tests and studies on urban transport systems. In addition, implementation of using catalytic converters and compulsory unleaded fuel in accordance with international standards has already been in affect since 2002.

Although the recent hike in the oil price, which was imposed by the UAE's government as a result of a record high in the oil price, which reached 55 \$US/barrel, the price is still considered to be lower than other major developed countries especially EU countries [40]. Therefore, a gradual annual increase in the oil price should be adopted with respect to the

country's annual inflation rate, hence leading to lower utilization of the fossil fuel and vehicle utilization growth rate. The government should emphasize more on the public transport services in terms of cost reduction, diversification of modes of transportation (adding subways or trams within city centers beside busses), and adopt schemes of reducing vehicle utilization such as car pooling. Moreover, the government must effectively introduce hybrid vehicles and fuel cell vehicles in the transportation sector to achieve fossil fuel savings as well environmental emission mitigation. A recent study suggested that the country could get a tremendous gain through utilization of fuel cell vehicles instead of internal combustion vehicles [18].

7. Conclusions

In this paper, an overall assessment of energy consumption and its environmental consequences in the UAE in the past two decades was carried out. The study covered all the major parameters influencing the country's energy consumption in terms of population growth, high urbanization rate and economic growth. The conclusions are summarized as follows.

- In the past two decades, the UAE's population increased by 5-folds as a result of increase in the number of expatriates joining the work force in the oil booming economy, where the country's GDP has risen tremendously from 30 billion $US in 1980 to 81 billion $US in 2003. Moreover, the country's economy is heading toward balanced and sustainable sources of income rather than a complete dependency on energy intensive industries.
- The UAE's primary energy consumption quadrupled in the past two decades as a result of a major increase in the population despite the country was going through an economic slump in the period from mid 1980s to early 1990s. By the same token, UAE's energy consumption per capita from 1980 to 2003, was considered to be the highest in the world with energy consumption ranging from as low as 9 TOE/capita to as high as 18 TOE/capita.
- As a direct consequence of UAE's high-energy consumption, carbon emission per capita was estimated at least twice as much as the developed countries such as the US and EU countries with an annual average emission of 10.5 TCE/capita. Surprisingly, this rate is at least 10 times higher than the world's annual average emission per capita.
- UAE's population is anticipated to double by 2015, if the country experienced similar economic growth as well as high living standards and increase in the number of expatriates to join the workforce that occurred in the past two decades. This alarming figure would lead the country's energy consumption and environmental emission to double within the same year.
- Although the country has taken certain drastic steps to reduce energy consumption and emission such as involvement of government organizations in environmental monitoring and impact assessment programs as well as enforcing environmental regulations on industrial, transport, residential and commercial sectors, energy consumption and environmental pollution are still considered to be the prime issue that have not been under a complete control.
- Local and national organizations in the country must deploy essential remedial measures in order to consolidate their positions in mitigating country's primary energy

consumption and environmental emissions. The proposed remedial measures are namely enhancing public awareness, achieving a lower population growth rate, maintaining a high economic growth rate, utilizing renewable energy resources, producing and utilizing hydrogen energy, implementing carbon sequestration technology and deploying energy management programs in various sectors.

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